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Abstract: We present our experience in the application of a new cybernetic system, TRIK, for control engineering education at university level. The TRIK system is composed of an embedded controller, analogue and digital input-output interface and an inertial measurement unit which can be easily programmed with visual and text based computer languages. The system can be efficiently used for robotic and control engineering prototyping and education. In the present paper, we describe and discuss various applications of the system in education covering basic control theory problems and advanced robotic system development. Our experience with TRIK has demonstrated that the developed system and corresponding curricula improves the efficiency of control engineering education at university level, and has significant potential to promote science and technology at secondary school level.

Keywords: Control engineering education; robotics; control systems.

1. INTRODUCTION

During the summit held at the BETT London educational exhibition in February 2016, a very interesting report was presented where the status of teaching modern technologies was analyzed. More precisely, the gap between modern technological levels and the level of tools used in educational institutions was evaluated. The authors came to the conclusion that in Europe the gap is about 15 years, for the USA it is about 18 years, and as much as 20 years in Russia. This mainly concerns school-level education. The obvious emerging crisis of the modern education system associated with the acceleration of the pace of development of modern technologies was discussed.

According to the experts of Japan Robotics Agency and International Federation of Robotics [JARA, IFR] we are close to the beginning of an era of service and personal robotics, leading to a shift in the technological paradigm. By many estimates, significant changes in this industry will occur in 2025-2030. A distinctive feature of this growth will be the widespread use of robotic devices and complexes in almost all spheres of human activity. It means that:

- robots will be omnipresent in the immediate vicinity of a person;
- robots will interact directly with people;
- robots will function in an anthropogenic environment specialized for human needs.

Note that the current situation is very different: in most situations it is strictly prohibited to be in close proximity with working robotic solutions.

Two problems arise with the coming boom in the service and personal robotics. First, it is necessary to prepare a large number of competent engineering staff with the relevant expertise in the field of algorithms, artificial intelligence, cybernetics, multi-agent groups control. The second point is very closely related to the first one. To ease the transition, we need to promote popular culture of using appropriate technical solutions. It can be illustrated by the era of computing we are living now. Computers are omnipresent and the person without basic computer using skills is considered almost illiterate.This is similar to a gap in ICT education in the early 1980s when PCs were already being used in business, and later when basic skills in PC-usage became a strict requirement for non-IT professionals. Therefore, nowadays there is a request from society to form competencies required for the emerging markets of the future.

2. THE CONCEPT AND IMPLEMENTATION TOOL

In addition to problems that arise with the rapid development of technology, there are more global trends in the field of education. Worthy of note is that there is a general drop in motivation to study science education, lowering the quality of applicants, and, as a consequence, creating a total drop in the percentage entering the engineering profession. In 2008, the Cyber-Physical Laboratory was formed in St. Petersburg, Filippov et al. (2009), which incorporates the staff and faculty of the Department of Theoretical Cybernetics of St. Petersburg State University, the St. Petersburg State University Department of System Programming, Management of Complex Systems Laboratory IPMash Russian Academy of Sciences, St. Petersburg President Lyceum №239 and subsequently many others. The efforts and experience of electronics and software engineers were brought together to develop novel educational methods to be employed in robotics education. The task from the outset was to organize joint activities between pupils and students when working on projects, Filippov et al. (2011). In this case, students act as scientific advisors. At the same time, students involve pupils in work on projects, which themselves operate at the university. This aspect is particularly important in high school, that is, in this age of the students it is very important to see the prospect of further development, Filippov et al. (2012).

That is, pupils started with edutaiment and through project based learning evolved to work in the University projects under the supervision of the students and professors.

To implement this approach, we tried many tools commonly used in STEM Robotics, the most popular of which are LEGO Mindstorms NXT / EV3, Arduino and Raspberry Pi. Despite the success stories we have had (like in A.Pilat, et al, 2009), experience has shown that children's robotic kits are ideal for first steps in STEM, but do not allow the implementation of amateur projects. Single board controllers like Arduino and Raspberry Pi require technical competencies that students do not have. The result is a gap between the easy to use kits and tools for undertaking complex projects. This is why it was decided to implement our own platform, TRIK, Terekhov et al. (2012), which is suitable for teaching students and for students in project activities.

In addition to the educational aspect, the aim was set to make an effective tool for scientific investigations and technical developments. It is impossible to assemble the Vostok rocket using a stone hammer, and for rapid prototyping of modern intelligent robotic complexes and multi-agent systems, one needs an intelligent tool. The TRIK project emerged precisely as such a tool, one of the main requirements of which was simplicity and ease of use, regardless of the level of the user's competencies: both for beginners, for professionals, and for developers. For beginners it provides a low entry threshold, and for professionals an expandable set of features that reduce development time. It should be noted that any known robotic kit does not have the technical and educational properties listed above. The only solution has been to create a set from scratch.

After the problem and requirements analysis, the OMAP L-138 chip was chosen as the main microcontroller of the hardware controller. It is the dual core System on Chip (SoC) ARM+DSP processor running at 400MHz. It's undoubted advantage is the presence of the ARM9 core for the OS and user programs and in parallel the Floating Point VLIW DSP core for signal processing (such as real-time audio/video processing). In addition, there are various onchip capabilities on this SoC: DDR2 memory controller, MMC/SD card interface, 100 Mbs Ethernet controller, host USB controller, Video Port Interface, Real-Time Unit Subsystem etc. See Fig.1 for the photo of the TRIK controller.

Fig. 1. Photo of the TRIK module

Accordingly, the developed board has received a large number of new features:

- dual core ARM+DSP processor;
- 64MB DDR2 RAM;
- flash 128 MB;
- Bluetooth;
- Wi-Fi;
- 3” color TFT LCD display;
- ability to operate 16 motors;
- ability to connect 12 digital and analog sensors;
- 2 video inputs;
- 2 extensions slots;
- microSD card slot.

All these capabilities are sited on aboard 8 cm wide by 12 cm high. See Fig. 2 for the photo of the first example of this board. As a result, we have a powerful tool that can be used for more than teaching students. This hardware controller is suitable for industrial prototyping problems too. The board has already attracted the interest of institutes and university research groups due to its characteristics.

The main advantage of this board is the combination of powerful computing capabilities, a rich periphery, and, last but not least, the ability to quickly connect a wide range of motors and sensors. The last is performed with the least number of adapters, if any are needed. At the very least, the using a “soldering iron” is reduced to almost zero even in research and creative tasks.

In contrast with popular platforms like Arduino and Raspberry Pi, TRIK set allows to solve complex tasks like Simultaneous Localization and Mapping (SLAM) out-of-the-box. Arduino does not provide enough computational power, whereas Raspberry Pi demands numerous adapter boards to plug motors and sensors. Additional adapter boards mean knowledge in electronics inaccessible to a wide range of students. TRIK set allows to focus on the heart of the problem we are solving without dissipating our attention to endless small technical problems (overcurrent protection, PWM fine tuning, video/audio processing and so on).

Another important advantage is that a large number of software solutions for a wide range of applications are designed for these controllers. The board itself runs on the open operating system Linux, adding new features and abilities. At the same the development or porting of new software components is a relatively simple procedure.

3. THE TRIK SET EDUCATIONAL EXPERIENCE

In practice, the implementation of two lines in parallel. The first line is educational and provides design, programming and learning of basic algorithm control skills. The conclusion of each educational topic is robotic competitions: line kegelring, Sumo robots, Relay Races and etc. [ROBOFINIST 2016 https://robofinist.org/en/competitions/types/]. The second line is project base learning which can be started in parallel and the conclusion of each project group is a speech with the presentation. In addition, this line is very useful for educational camp sessions, Kapitonov (2016), Stone (2017).

The main point of the TRIK project was to provide an answer to the demand of the educational community for an educational tool that can help bridge the gap between children robotics kits and half-professional one board controllers which is why an important part of the project is curriculum conception. This eventually allowed the development of the concept of the school metasubject lab, which was tried out in the lyceum № 419 in St. Petersburg. Currently, there are over 12 sites in Russia developing and approving new educational approaches and as result the TRIK project became a part of the Children's Technology Parks Federal Program. A distinctive feature of the approaches developed is teaching “from top to bottom” which is based on Model Based Design software TRIK STUDIO, Luchin (2012). The essence of this approach involves gradually descending from the top down, but starts testing even at the first stage. The virtual model which is built in TRIK Studio IDE allows you to debug the program before uploading it to the robot (Fig.2).

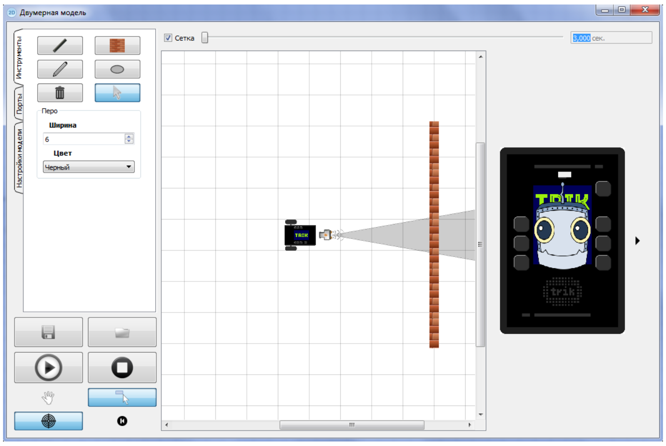

Fig.2 Virtual screen of TRIK STUDIO

This approach allows to quickly overcome difficulties that usually arise when someone starts programming a real robot. In addition to this, programs created with visual blocks and connections ease the understanding of simple algorithmic structures and their combinations (see Fig.3).

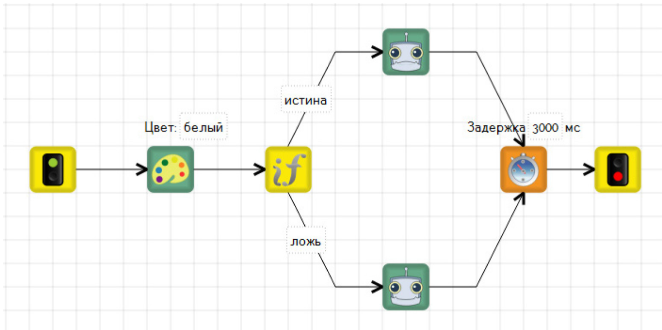

Fig.3 Behaviour Diagram

As a result, before downloading software on the robot a student go through two stages of development: fixing syntax errors, given by syntax analyzer and code generator, and fixing algorithmic errors that were detected during the simulation. Once first programming experience is gained, students may move to plain text JavaScript. This feature enables a smooth transition to a different programming language, allowing to compare various algorithmic structures implemented with different approaches (Fig.4)

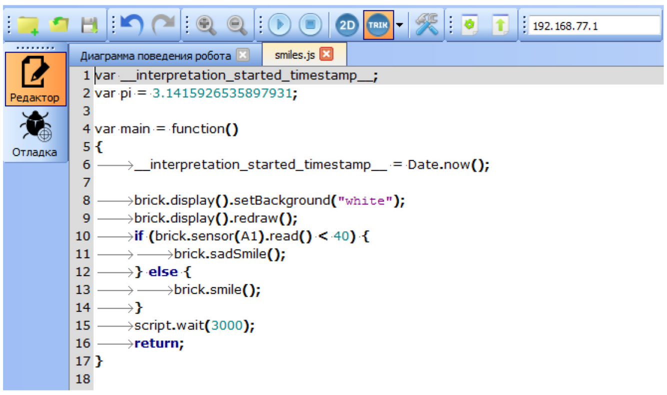

Fig.4 Generated Code

The next distinctive feature of the approach we propose is the direct integration of the foundations of the control theory in the educational course. In this case, a basic acquaintance, for example, with a PD-controller occurs in the fifth class (Fig 5). The control theory in a discrete form can be easily integrated in the basic mathematical program of secondary school, with such topics as linear and quadratic equations, geometry, trigonometry, etc. But most importantly, it becomes possible to demonstrate how mathematics work in real life.

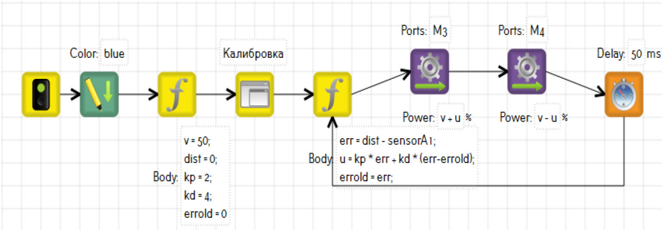

Fig.5 The implementation of PD in TRIK STUDIO

As an example of a small project that fascinates children we can cite a ``light saber'' that can be made with a LED band, few metal parts and the TRIK controller. The ``light saber'' changes its color depending on the angle of inclination. Mathematically it essentially means to compute an angle of a right triangle. This project is a fun way to show the basic math behind a smartphone changing its orientation from portrait to landscape. It is an opportunity to demonstrate in an accessible form how an accelerometer works and, more importantly, why should someone bother to study math and science.

High computational power of the TRIK controller allows for onboard real-time audio and video processing, and to make a large number of high-level functions that allow pupils to use complex algorithms (Fig. 6).

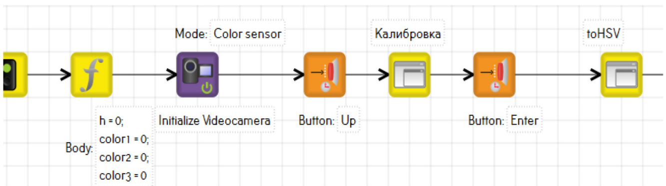

Fig.6 Video processing in TRIK STUDIO

Usage of high-level blocks for video processing allows students to increase the number and complexity of the competitions in which they can participate. The video module can be used both as a color sensor and as a line detector, however it does not matter whether is it solid, inverted or discontinuous. As a result, this knowledge is very useful in the subsequent project activities. It should be noted that TRIK is open source platform, allowing students to inspect and modify algorithms if they desire to improve them. The last fact has a very positive effect on the process of early career guidance.

These techniques in different variations were tested in three All-Russian robotic summer camps (2014-2016) in St. Petersburg, in the AYcamp 2014 in Moscow, on the design session of the Educational Centre Sirius in Sochi in July 2016, and seven robotic camps in London (2015-2016) at the London School of Mathematics and Programming [www.londonsmp.co.uk]. In addition, over 80 workshops have already taken place in different regions of Russia.

In St. Petersburg, there are free courses for teachers, with the support of robotics center at the President's Lyceum №239 and in collaboration with the center for raising qualifications in "Educational Technology". At the time of writing, four TRIK training courses have already been successfully completed to improve the qualification of teachers in robotics. The training was attended by over than 100 people and 40 more teachers have been trained at the University of Lorraine (ESPE de Lorraine), France.

4. EXAMPLES OF STUDENT PROJECTS

Due to TRIK's versatility and flexibility, it is an excellent choice of a platform to use for student projects. Rich onboard peripheral functions allow experiments in very different settings. For example, it has on-board encoder and power motor ports, so it is straightforward to control standard equipment such as linear servo carts for inverted pendulum units. However, we can go beyond it, and propose even more attractive subjects of study.

Let us show you three examples of master thesis projects defended at the University of Lorraine, France. These examples illustrate the versatility of the platform and the range of possibilities it provides for the learning process. The small car in the image below is equipped with a lidar and camera, and is designed for testing different simultaneous location and mapping approaches like Zlot et al. (2009), (Fig. 7).

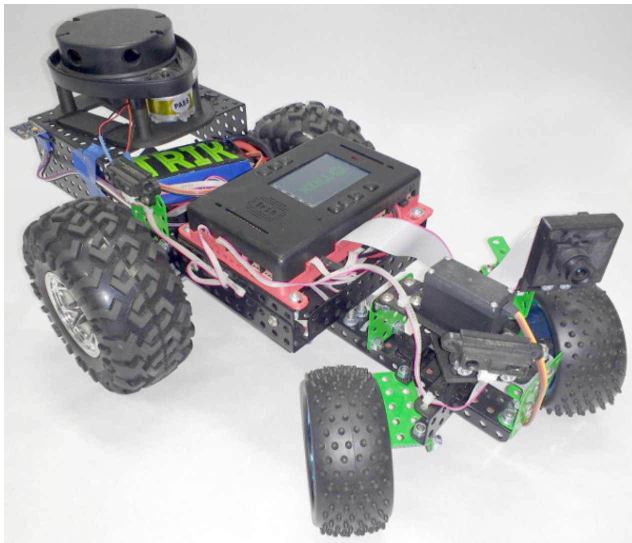

Fig. 7 Car with lidar and camera

The image at the Fig.8 shows a quadruped built with a TRIK controller and Dynamixel servo motors. While it is straightforward to make a hexapod walk, quadruped movement presents some difficulties, thus it is a great project to study central pattern generators, Righetti et al. (2009).

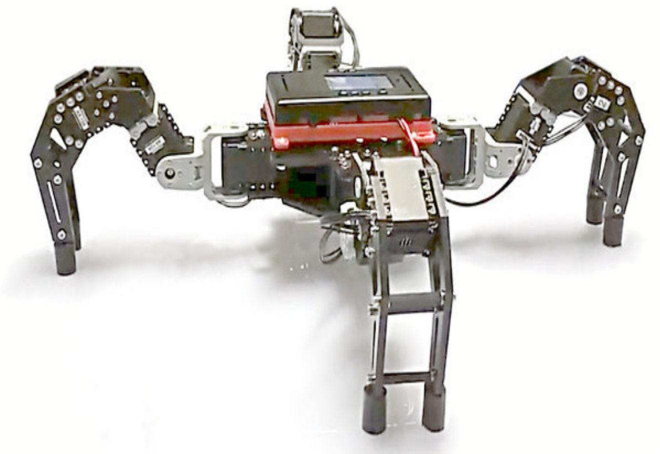

Fig. 8 Quadruped on TRIK

The third project we present is a small rover shown in Fig.9. It is an attempt to build a robot for the Eurobot National French qualifications, whose localization procedure used three independent acoustic beacons and a pair of microphones to receive the pings from the beacons, similar to the method proposed in Ogiso et al.(2015).

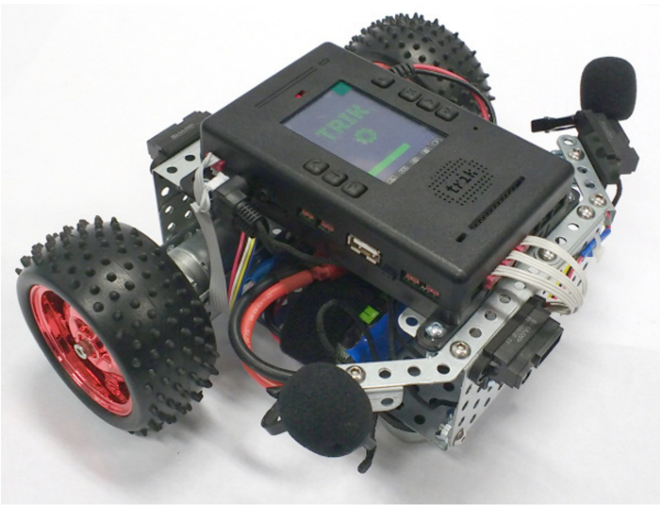

Fig 9 Cart for Eurobot Competition

Experiments with the TRIK platform received very warm and positive feedback for our Equal Opportunity project. The idea is to bring university students to schools in underprivileged areas. During the year, on a regular basis, students organise a small series of lectures followed by practical sessions. The hope is that by showing interesting things that can be done at university, young people from underprivileged backgrounds will pursue further education at university level.

TRIK sets are used in four schools by students of ESSTIN (École Supérieure des Sciences et Technologies de l'Ingénieur de Nancy), and these projects have attracted the attention of socially disadvantaged teens. We are proud of our Equal Opportunity project, and have already seen several students from these schools apply to ESSTIN.

5. SAINT-PETERSBURG INTER-UNIVERSITY ROBOTICS PROJECTS LABORATORY

The laboratory was founded as a joint initiative of the TRIK project and JetBrains company [www.jetbrains.com] to support related interest groups of students and the faculties of leading local universities. Being well known for their achievements in the ACM International Collegiate Programming Contest and strong enough in software development, lots of students declined to choose robotics and cybernetics related areas because of a lack of electronics engineering skills and interest to this area. With the use of TRIK controllers, the number of undergraduates', bachelors' and master's robotics and cyber-physics related projects at the Software Engineering department of Saint-Petersburg State University increased from 3 in 2010 to 37 in 2016. We take into account all projects which were inspired by the introduction of robotics into education, rather than those directly related to the construction of motion planning and other algorithms

For example, the first robot running generic control software on Mono with F# programming language was possible only because we introduced the platform that successfully managed away electronics engineering problems and allowed a sole focus on software technologies, see Kirsanov et al, 2014. For a significant number of projects (19 out of 37) students were free to choose a DIY hardware platform (Raspberry Pi 1/2/3, Intel Gallileo, Odroid XU4, Arduino), but 17 of 19 chose TRIK because it was "simple enough to create an autonomous vehicle in my language of choice".

Now project areas vary from pure CS research such as the "Formal specification of motion planning" to systems programming, f.e "Dynamic executable code generation for heterogeneous IoT environment", see Soshnikov et al, 2014.

6. CONCLUSIONS

We are in the beginning of a new cycle of the the scientific progress acceleration and we witness the gap between modern technological level and the level of tools used in educational institutions. Last time we witnessed a similar situation with the arrival of computers. At the time, the difficulty was overcame by developing user-friendly interfaces and user-experience technologies.

To overcome the difficulty, we must adapt our pedagogical approaches, however it is impossible to adapt retraining of hundreds of thousands of teachers throughout the world to match changes of technological paradigm. The choice of educational platform is crucial in the current race of technologies. TRIK platform offers flexibility, power and ease to use.

TRIK platform can be used as a very vivid illustration of the reason to study science, thus putting fun and interest back into the teaching process. In addition to the school course, it gives exciting possibilities to complement and enhance school education, keeping pupils in touch with modern technologies.

TRIK platform is developed as a link between the school and the university. First of all, with the TRIK's aid students can focus on the heart of their scientific projects, thus boosting the development speed. Then, with the experience gained in the university, it is easy for the students to use TRIK to animate various projects at the secondary school level. Involving pupils in scientific projects creates the synergy effect drawing more better qualified students to engineering schools.

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